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Development and Testing of Two Towed Volumetric Hydrophone Array Prototypes to Improve Localization Accuracy During Shipboard Line-transect Cetacean Surveys

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Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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INTRODUCTION

Passive acoustic monitoring (PAM) of cetaceans using towed hydrophone arrays is a principle component of shipboard cetacean population surveys conducted by the National Marine Fisheries Service (NMFS). The traditional array design used by the NMFS includes a linear configuration of hydrophones housed inside a castor oil-filled polyurethane tube that is towed behind the ship while traveling at approximately 10 knots. Linear arrays are excellent tools to detect vocal cetacean groups and estimate their location during real-time operations. Conical bearing estimates are obtained using the time difference of arrival (TDOA) between individual cetacean sounds on two hydrophones in a linear array. Once bearings to the animals converge relative to the ship, a perpendicular distance estimate from the transect line to the animals can be determined (Rankin et al., 2008). Depending on the circumstances, the acousticians may then direct the ship to turn in order to guide the visual observers to the location of the animals. However, acoustic tracking can be challenging due to the limitations of the bearing information from the linear array. The convergence of conical bearing angles cannot discriminate between signals originating from left, right, up or down. For dolphins that primarily vocalize in surface waters, the up/down ambiguity is not a large concern, but the left/right ambiguity often requires more ship time to determine the correct location of the animals. For deep-diving species like beaked whales, the ambiguity in declination angle can result in a biased estimate of their perpendicular distance from the transect line (when projected to the surface). A more efficient and precise localization method would offer better results and more accurate data for several cetacean species.

The three-dimensional configuration of hydrophones in a volumetric array has been shown to address many limitations of the linear arrays for some species (Zimmer, 2013). Jay Barlow developed two predecessors to the current prototypes of towed volumetric arrays (Fig. 1). Field tests in 2011 and 2012 provided three-dimensional localization at speeds of 6-8 knots. These designs provided acoustic bearings to animal groups, without the left/right ambiguity and provided the approximate depth of the animals (Southall et al., 2012). However, these designs showed poor acoustic performance at higher speeds above 6 knots, presumably due to turbulent flow and vibrations. The designs also rotated during turns, thus causing torque on the tow cable and uncertainty in the array orientation. Despite the shortcomings of these designs, the concept of a light-weight, towed volumetric array showed merit.

We present the results of a project aimed at improving the hydrodynamics of the volumetric array design for towing at faster speeds of 10 knots from large research vessels. Two different designs were selected for the prototypes, henceforth known as the torpedo array and the X-array. We explain the theory behind the design considerations for each prototype, the sea trial results and subsequent modifications, and discuss improvements to future volumetric array designs.

Figure 1.--The volumetric array predecessors included a 'box-kite' design that provided three-dimensional localization, but did not perform well at speeds faster than 8 knots.

METHODS

Volumetric Prototype Design

NMFS scientists from the Southwest Fisheries Science Center (SWFSC) and the Pacific Islands Fisheries Science Center (PIFSC) collaborated with marine engineers at the Scripps Institution of Oceanography Marine Physical Laboratory (MPL) to develop a towed volumetric array prototype that incorporated a balance of multiple factors that complied with the collection of NMFS PAM data. We specified four design criteria:

1. Include a spatial arrangement of four hydrophones capable of receiving sounds from any direction.
2. Maintain a stable orientation, minimal noise, and depths between 6 and 8 m while towing at 10 knots.
3. Easily handled by a single person during the deployment and retrieval.
4. Compatible with the existing NMFS PAM system (Rankin et al., 2013).

Prototype Drawings and Performance Modeling

Guided by the above design criteria, the torpedo array and X-array prototype designs were developed and illustrated using SolidWorks CAD modeling software (Fig 2; Dassault Systèmes, 2010a). SolidWorks provided a visual representation of the prototypes that allowed manipulation and adjustment of the angles, lengths, shapes, contours, and overall size of both designs. The universal design features included four hydrophones with preamps fixed inside a rigid, hydrodynamic structure to provide a specific configuration necessary for precise three-

dimensional localization. The spatial separations of the hydrophones were carefully considered since they would affect the bandwidth and frequency of sounds to be localized using TDOA.

Once prototype drawings in SolidWorks were finalized, MPL engineers tested the designs using SolidWorks Flow Simulation software, FloWorks (Ahmed, 2014; Dassault Systèmes, 2010b). This intuitive computational fluid dynamics tool calculated the spatial distribution of the flow velocities and hydrodynamic pressures associated with the prototype design when immersed in a steady-state background fluid flow. Flow velocities of 10 knots were used to simulate the flow of water over the array (Fig 3). The direction of flow over the array was changed to various angles, including 0, 1, 2, 4, and 8 degrees, to predict the areas prone to creating turbulence on the array with the different "angles-of-attack." FloWorks simulation results directly influenced the final structural dimensions of the array prototypes.

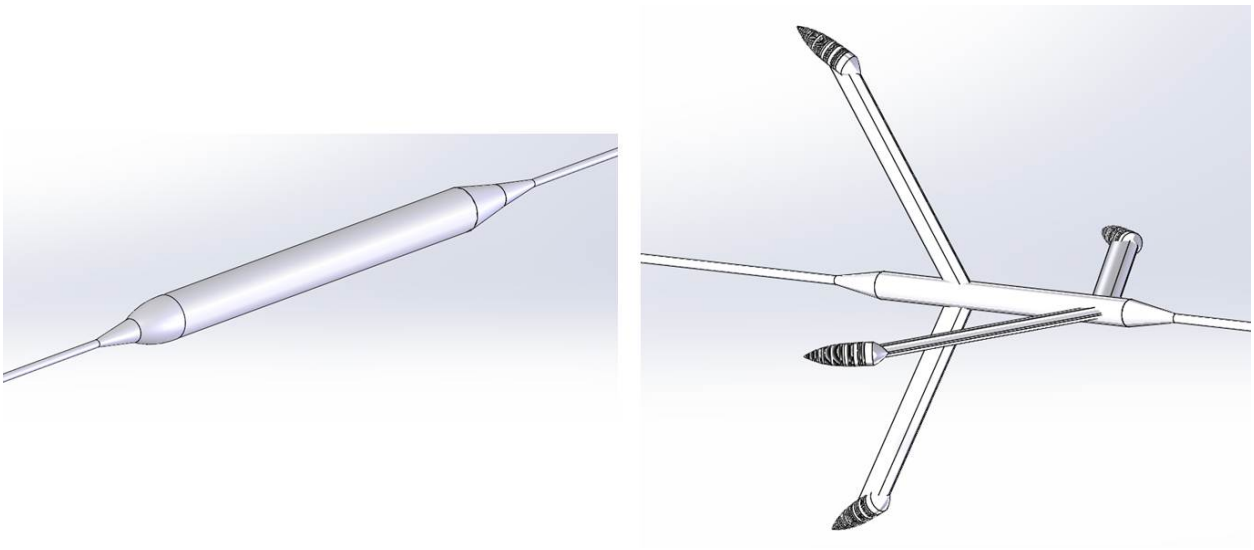

Figure 2.--SolidWorks drawings of two volumetric array designs, the torpedo array (left) and the X-array (right).

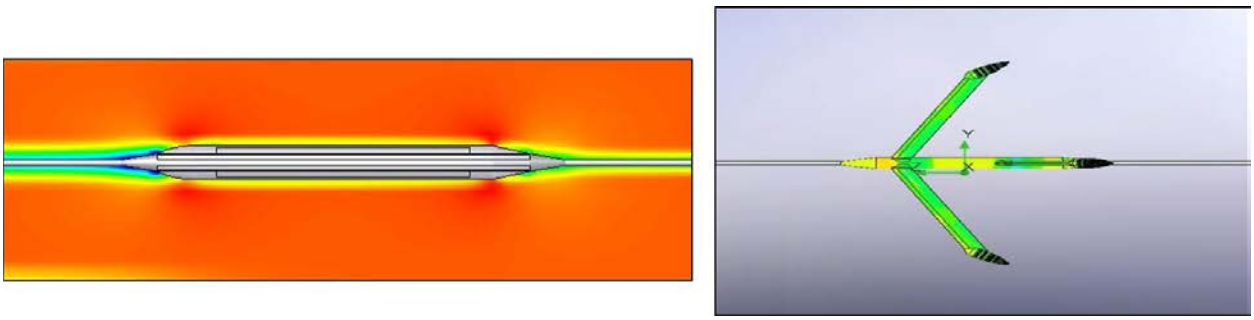

Figure 3.--Images from selected FloWorks performance models for both prototypes modeling different variables using flow velocities of 10 knots.

Sea Trial Testing of Prototypes

The sea trials provided opportunities to test the volumetric array prototypes from a variety of different vessels. Crucial information was collected for evaluating the performance of each prototype and allowed for issues to be identified to implement the necessary modifications immediately in the field or afterward in the lab.

For all sea trials, continuous wav file recordings were collected using PAMGuard (Gillespie et al., 2008) to evaluate the flow noise levels at different speeds. Flow noise levels were evaluated with aural and visual comparisons of spectrograms as well as a spectral analysis using the sea trial recordings. Noise spectra were compared between both prototypes and the linear array when possible.

Accelerometers built into each prototype recorded continuous analog data to measure the 'X' and 'Y' rotational orientation of the array prototypes while under tow. The accelerometer data stream was collected in real-time using a data acquisition unit (USB-1208LS; Measurement Computing) and logged to a database using special modifications within PAMGuard's hydrophone array configuration module. The raw accelerometer voltage data from each prototype were converted to degrees of rotation. The converted data were then analyzed by plotting the degrees of rotation over time.

The array depth was measured using an internal pressure sensor housed in the body of the prototypes and external sensors were used when possible for validation purposes. Internal sensors provided a real-time data stream of depth measurements while depth data from external sensors were evaluated upon the completion of the sea trial.

Modifications of Prototypes

Upon completion of the data analysis for each sea trial, various modifications to the prototypes were implemented as deemed necessary. Prototype modifications were intended to decrease flow noise levels and improve the stability of the prototype by minimizing the rotational movement. Once a series of modifications were completed, the prototypes were tested during subsequent sea trials.

RESULTS

Volumetric Prototype Design

Construction of one torpedo array and two X-array prototypes was completed in March and April 2014, respectively (Figs. 4 and 5). Although the torpedo array and X-array designs differed dramatically in their structural materials and general dimensions, they fulfilled the

same basic design requirements necessary for NMFS PAM data collection. Both designs could be operated as a stand-alone or in-line unit (Rankin et al., 2013) with dimensions that allowed for a single person to manage the deployment and retrieval processes (Fig. 6). Drawings of each array prototype are provided in Appendix A.

Several components were included in both array prototypes to make them compatible with current NMFS PAM systems, including a High Tech, Inc. hydrophone (HTI-96-MIN Exportable) with an internal pre-amp providing 20 dB of gain and a 1 kHz high-pass filter. Single-sided output signals from these hydrophones were amplified to 40 dB with a second pre-amp that provided differential output. An Adafruit triple-axis analog accelerometer (ADXL335) was included in both prototypes to measure the rotational movement as well as a Keller America pressure transponder (Model # PA7FLE) for depth measurements while under tow. Underwater connectors from Teledyne Impulse (MHDM-26-BCR) were also incorporated. More details about these components are provided in Appendix B.

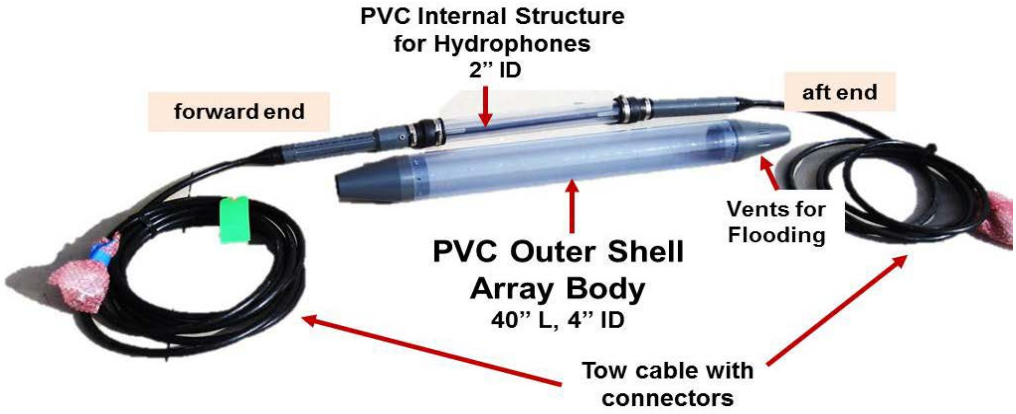

Figure 4.--The general dimensions of the torpedo array with the outer shell disassembled from the internal structural hydrophone housing.

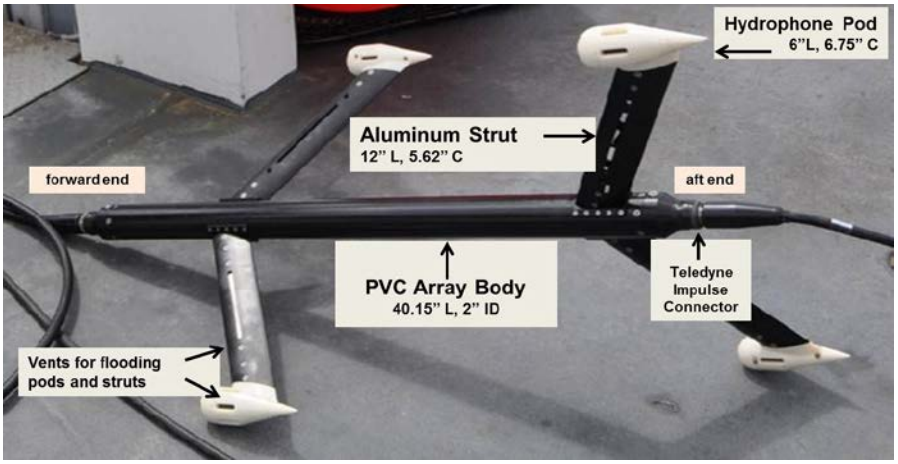

Figure 5.--The fully assembled X-array prototype with general dimensions and components.

Figure 6.--Acousticians handling the volumetric array prototypes, torpedo array (top) and X-array (bottom), during a sea trial.

Torpedo array prototype design. The torpedo array design included a streamlined shape with four hydrophones mounted inside a cylindrical PVC shell in a tetrad configuration. An inner PVC tube housed the electronics, and the space between the inner tube and outer shell was designed to flood with seawater via small vents in the aft nose cone. The spacing between the four hydrophones is smaller compared to the X-array, therefore limiting localization to short, broadband vocalizations, such as echolocation clicks.

X-array prototype design. The X-array hydrophones were housed inside nacelle pods affixed to anodized aluminum struts that protruded from the array body in an X-shaped orientation. Both the pods and struts were designed to flood with seawater to decrease the overall in-air weight. Each strut was fitted to a block that screwed directly to the oil-filled, PVC array body. A gasket between the block and array body provided a waterproof seal. The lower strut contained a lead weight bar to provide stability to the prototype while under tow. The configuration of the struts created a large tetrad for the localization of frequency-modulated signals, such as dolphin whistles. Electronics (differential pre-amps, depth sensors, and accelerometer) were packaged inside the array body.

Sea Trial Prototype Testing

In total, the prototypes were tested seven times during four sea trials in 2014 (Table 1). The sea trials included the Passive Acoustic Sea Trials (PAST 2014), the NOAA Ship R/V *Reuben Lasker* Shakedown Mission Trial (*Lasker* Shakedown), the Southern California Behavioral Response Study (SOCAL-BRS), and the California Current Cetacean and Ecosystem Assessment Survey (CalCurCEAS). When possible, a linear array was also deployed to provide baseline data for comparison purposes. Table 1 provides a complete summary of each sea trial, including the tests performed, the results, and the subsequent modifications that were implemented.

The sea trials focused on assessing the flow noise levels and stability of each array prototype. Flow noise levels were assessed and compared primarily during tow speeds of approximately 5 knots to obtain baseline measurements. The stability of the volumetric prototypes was tested at a variety of speeds, ranging from 3 to 10 knots. The accelerometer data stream collected during these tests was intended to provide information about the rotational movement of each prototype in real-time and post-analyses. Due to the different completion times of each array prototype, the modifications that were made, and other logistical constraints, both prototypes were not available for testing on all sea trials.

Table 1--Array prototype field test results and modifications are summarized for each sea trial.

Sea Trial Name	Date	Vessel Name	Vessel Length (ft)	Arrays Tested	Torpedo Prototype		Modifications Post-Test	X-Array Prototype		Modifications Post-Test
					Tests	*Results*		*Tests*	*Results*	
PAST 2014 Leg 1	3/28/2014	MV *Pacific Voyager*	65	torpedo, linear	tow speeds of 3-7 kts	similar flow noise to linear array, high rotational movement	used dish soap to saturate hydrophones during flooding, 4 fins added to aft end	NA	NA	NA
***Lasker* Shakedown**	5/21/2014	RV *Reuben Lasker*	209	torpedo, X, linear	tow speeds of 3-7 kts	similar flow noise to linear array, minimal rotational movement	None	tow speeds of 3-7 kts, single 20 degree turn at 7 kts	variable noise present on all hydrophones and increased with higher speeds	potted hydrophone pods with polyurethane, secured cables inside struts, covered strut vents with tape
PAST 2014 Leg 2	7/16/2014	MV *Pacific Voyager*	65	torpedo, X, linear	tow speeds of 3-7 kts	similar flow noise to linear array, minimal rotational movement	None	tow speeds of 3-7 kts	flow noise improved for modified hydrophones/struts	None
SOCAL-BRS Leg 1	7/27-8/7/2014	MV *Truth*	65	torpedo	tow speeds up to 8 kts	15 acoustic detections, array towed quietly with good stability	None	NA	NA	NA
CalCurCEAS Leg 1	8/6/2014, 8/9/2014	RV *Ocean Starr*	171	X	NA	NA	NA	towed 10 hours at speeds up to 10 kts, conducted turns at varying angles	variable flow noise levels, accelerometer non-functional, twisted tow cable, significant rotational movement	added 90 cm struts in 'upper' and 'lower position, filled lower strut with more bismuth lead
SOCAL-BRS Leg 2	9/7-9/20/2014	RV *Derek Baylis*	65	torpedo	tow speeds up to 9.5 kts	38 acoustic detections	None	NA	NA	NA
CalCurCEAS Leg 4	11/13/2014	RV *Ocean Starr*	171	torpedo, X	STAR-ODDI sensors deployed, towed 200 m behind ship at speeds up to 9 kts	stable up to 9 kts, but roll angle changed with speed, high flow noise above 8 kts, variable depth: 4.5-10.5 m	None	STAR-ODDI sensors deployed, towed 200 m behind ship at speeds up to 9 kts with 2 turns	stable at 5-9 kts, flow noise persisted, whining noise caused by covered vent, variable depths: 5.5-14 m	None

Flow noise test results. After completing modifications to the torpedo array (Table 1), optimal flow noise levels occurred at 5 knots that were comparable to the linear array (Fig 7). The torpedo array was also successfully operated at 8 knots during the SOCAL-BRS, where flow noise increased, but remained at acceptable levels for detecting cetacean vocalizations. Speeds faster than 8 knots produced flow noise beyond reasonable levels on all hydrophones of the torpedo array.

The maiden voyage of the X-array prototype occurred during the *Lasker* Shakedown and resulted in flow noise levels that exceeded reasonable levels for detecting cetacean vocalizations (Fig 8a). After completing several modifications to the X-array (Table 1), flow noise levels improved for hydrophones with polyurethane-potted pods and modified struts (Fig 8b). Results from a spectral analysis of recordings collected during PAST Leg 2 compared the noise levels of both prototypes with the linear array at tow speeds of 5 knots (Fig 9). Noise levels for the X-array prototype remained higher than noise levels for the linear and torpedo array overall, particularly at frequencies below 7 kHz. Speeds faster than 5 knots resulted in higher levels of flow noise for the X-array.

Overall, we found flow noise levels to improve with the following modifications:

- Hydrophones should be isolated from direct contact with the water flow, e.g. housed inside an internal structure surrounded by oil or potted using an acoustically transparent material.
- If components are designed to flood with seawater, smaller holes or vents will allow for efficient flooding while minimizing associated noise while under tow.
- Any components of the array should be fully secured to reduce noise levels while under tow.

Stability and depth test results. Both prototypes were found to rotate (typically at higher tow speeds) and modifications were made to improve their stability. Four fins were added to the rear of the torpedo array prototype, including one weighted fin cast from lead-bismuth (Fig 10). Modifications to the X-array included increasing the upper and lower aluminum struts from 30 cm to 90 cm, and filling the upper strut with closed-cell foam and the lower strut with lead-bismuth.

Unfortunately, the accelerometer data was determined to be inaccurate during CalCurCEAS Leg 1 due to voltage fluctuations presumably caused by the 700-m length of tow cable used to test the prototypes. On subsequent tests, the voltage output of an accelerometer was converted to 4-20mA current output using separate voltage-to-current converter boards, but that arrangement was also problematic when the voltage in the array dropped below the 12V supply needed to power the converter boards.

Depth sensors placed inside the oil-filled space of each prototype provided erratic readings during most sea trials. Therefore, the exact depth of each prototype when towing at different speeds was unknown for most sea trials.

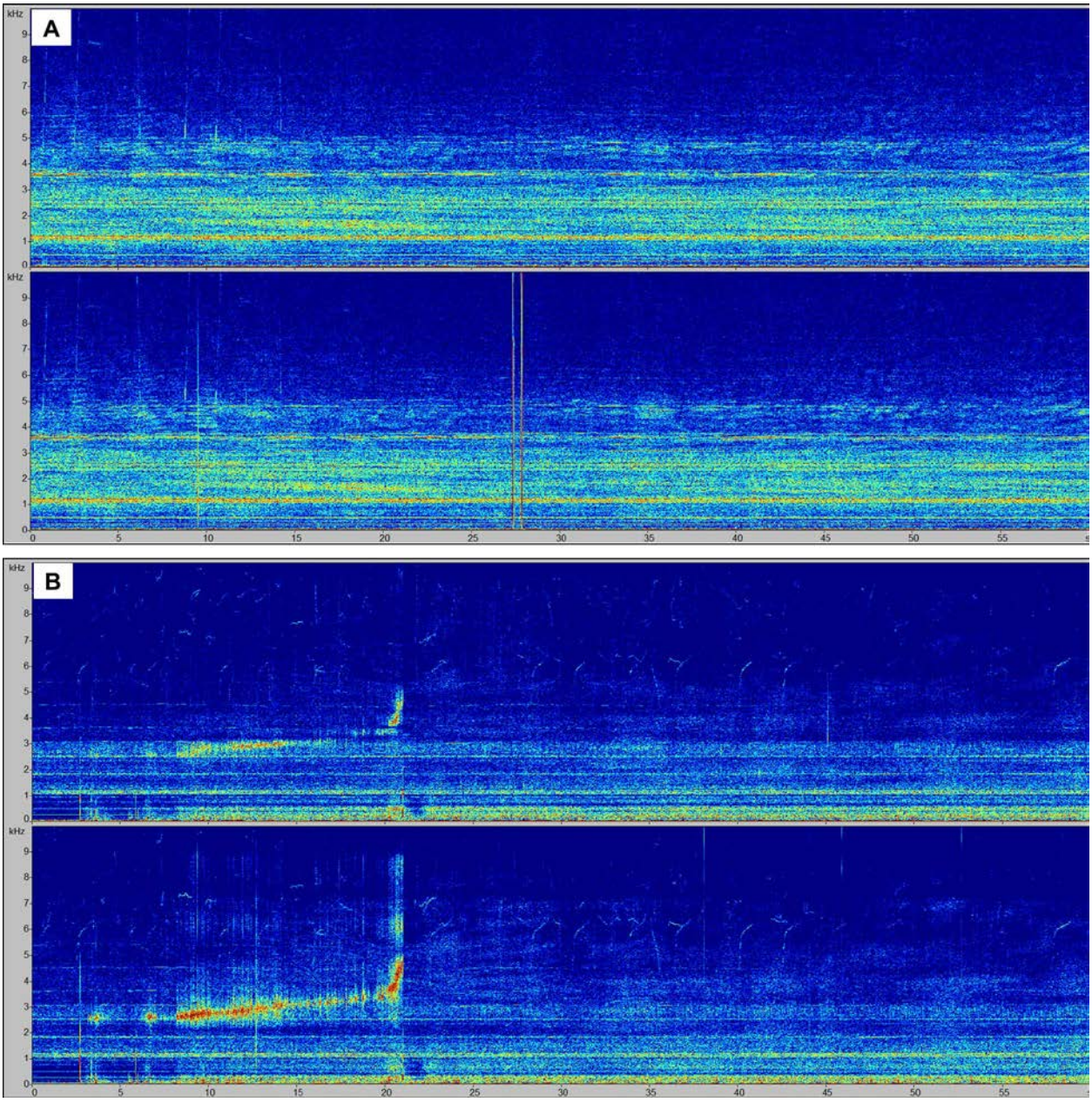

Figure 7.--Spectrogram of two channels (0-10 kHz, 58 s) from PAST Leg 2 showed comparable noise levels between the linear array (A) and the torpedo array prototype (B) when towed at 5 knots. The color ranges from blue to red, blue indicating low noise levels and red indicating high noise levels.

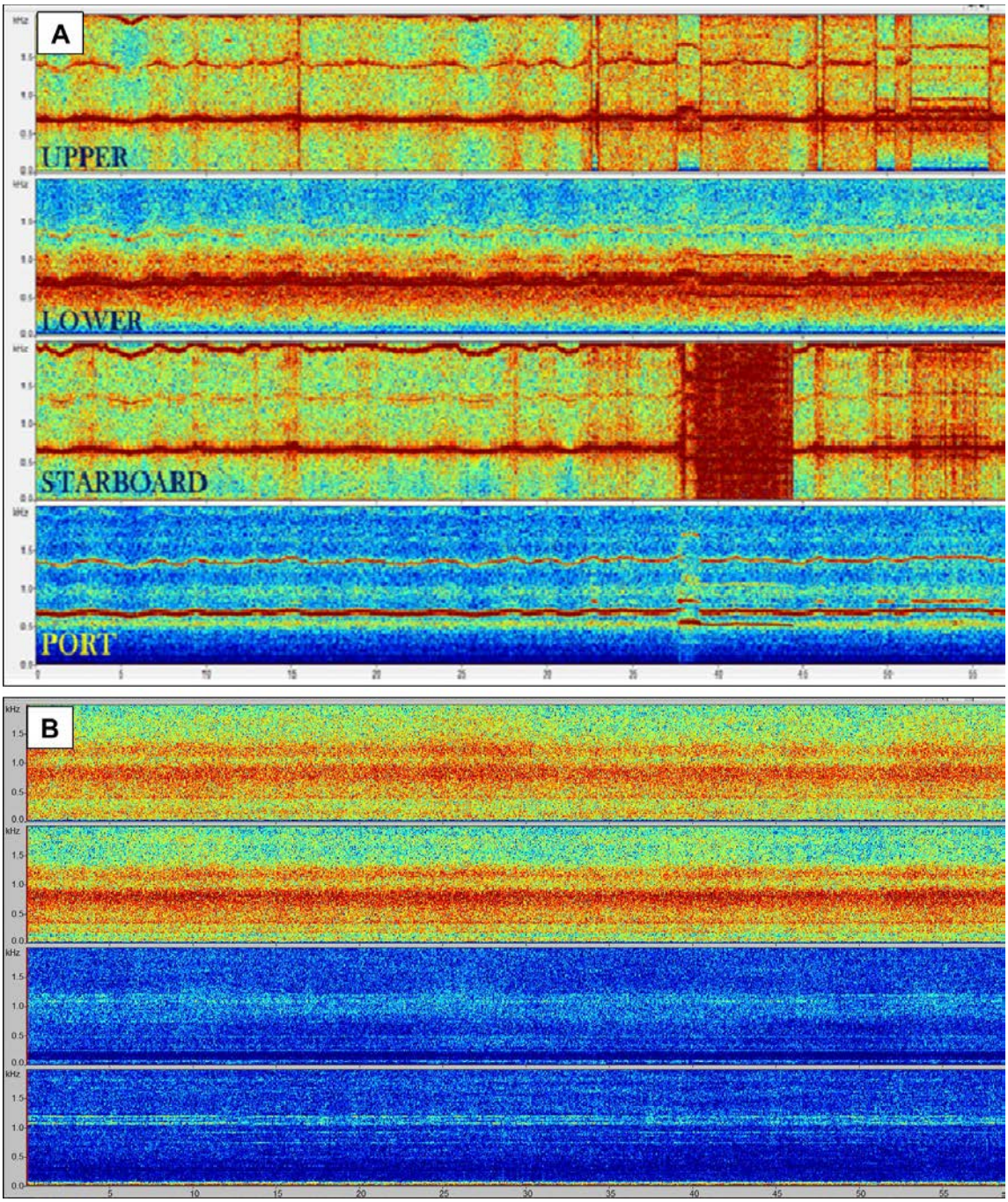

Figure 8.--Spectrogram of four channels showing lower frequencies (0-2 kHz, 58 s) for the X-array when towed at 5 knots during the *Lasker* Shakedown (A) and PAST Leg 2 (B). Modifications to selected hydrophone pods and struts (B, bottom two channels) showed vast improvements in flow noise. The color ranges from blue to red, blue indicating low noise levels and red indicating high noise levels.

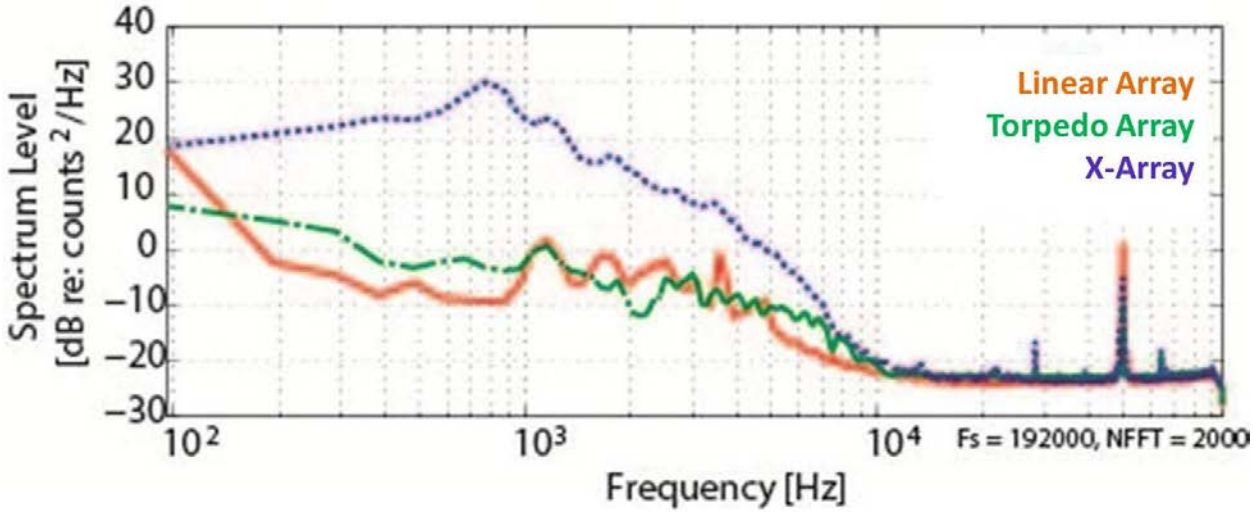

Figure 9.--Noise spectra for the linear array and torpedo and X-array prototypes when towed at 5 knots during PAST Leg 2. The X-array is relatively louder at lower frequencies below 7 kHz.

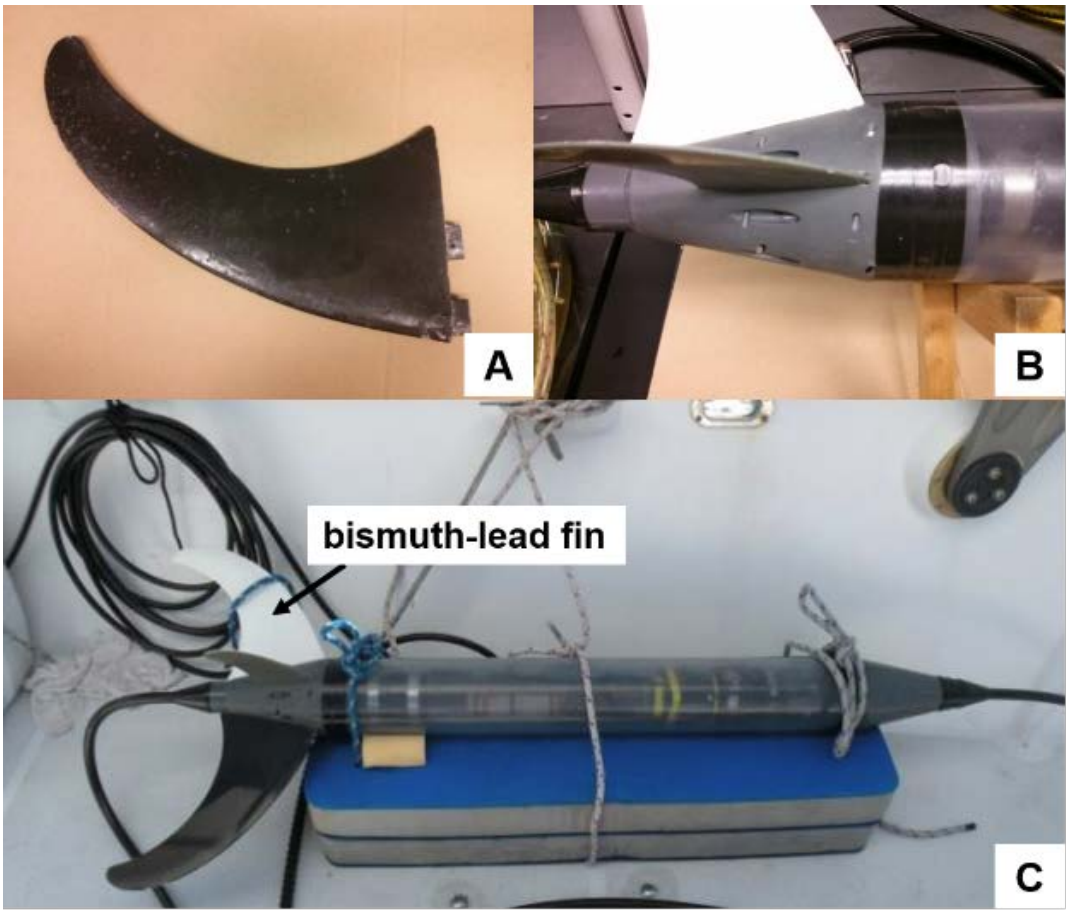

Figure 10.--Four surfboard fins (A) were attached to the aft cone (B) of the torpedo array to minimize the rotational movement. One modified fin was made of bismuth-lead (C).

Despite inaccurate accelerometer readings, it was obvious that significant rotational movement occurred on occasions when the tow cable would be twisted and the array would spin as it was retrieved, particularly for the X-array prototype. To resolve the discrepancy in the accelerometer and depth data, Star-Oddi data storage tags (DST magnetic; STAR-ODDI, Ltd) were externally attached to each prototype to measure their roll angle and depth during CalCurCEAS Leg 4. These data showed that both modified prototypes, the torpedo with 4 fins and the X-array with longer struts, exhibited a very stable orientation with variable depths at different speeds (Figs 11-12). Unfortunately, neither prototype was tested at the required 10 knots due to high levels of flow noise.

Overall, measurements of each prototype's stability and depth could be improved with the following:

- Utilize a current accelerometer that can transmit a reliable, real-time signal through longer tow cables.
- Incorporate internal or external pressure sensors that are able to provide accurate, real-time depth measurements.

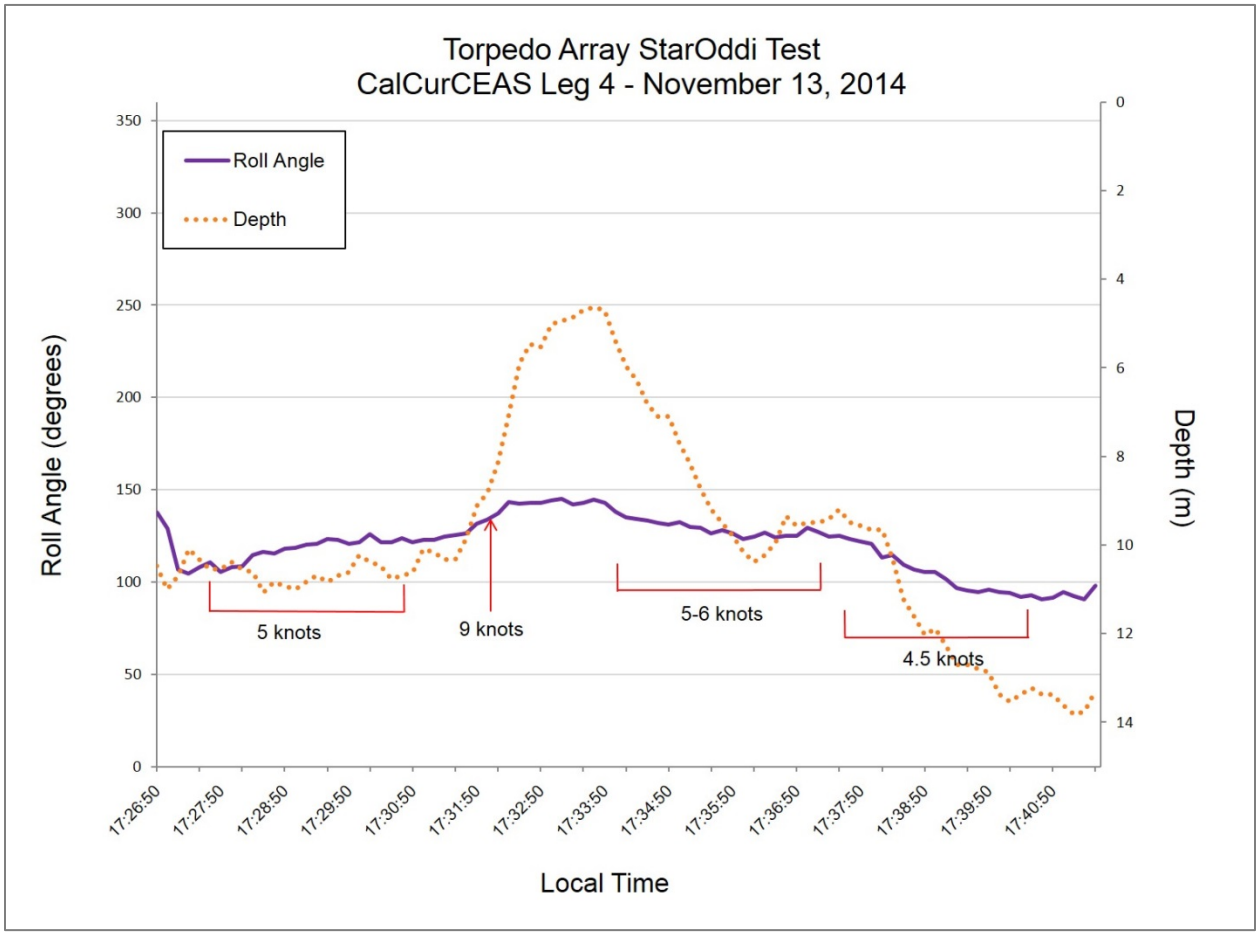

Figure 11.--Measurements of the roll angles and depths from the StarOddi DST magnetic sensor at various speeds for the torpedo array prototype.

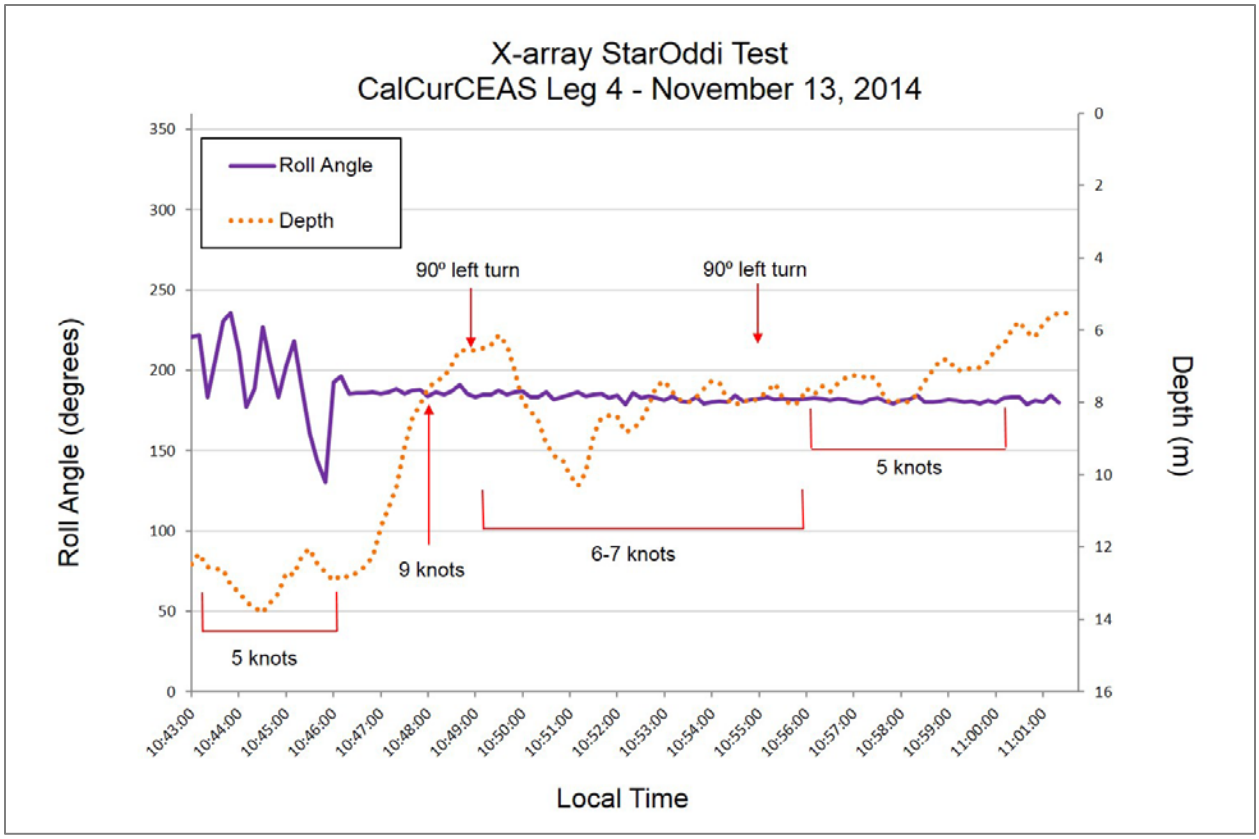

Figure 12.--Measurements of the roll angles and depth from the DST magnetic sensor at various speeds for the X-array prototype. Red arrows indicate times when the ship turned 90 degrees.

DISCUSSION

From the results of the sea trials conducted, the current volumetric array designs require further modifications to make them fully operational for NMFS cetacean surveys. Vast improvements in performance for both prototypes were gained over the course of this project and invaluable information was collected to provide guidance for future volumetric array endeavors. The major issues of flow noise and stability remain unresolved, but the sea trials offered insight into the limits and capabilities of both prototype designs.

While flow noise levels in the torpedo array were reasonable throughout the sea trials on smaller vessels, it is still unable to be towed faster than 9 knots from larger vessels without producing both increased flow noise and other unsettling sounds. The X-array showed significant improvements in flow noise up to 6 knots once the hydrophones were potted inside the pods. Faster speeds caused an immediate increase in noise, which may be due to the design of the pods or the overall array structure.

A different method in measuring the rotational movement of the volumetric array in real-time is necessary to achieve precise localizations of animal groups. A different accelerometer with 4-20mA current output and capable of operating on 10V supply current is recommended. The PAMGuard module developed to read the accelerometer data stream is directly tied to the localization algorithm and designed to correct the bearing information based on the roll angle of the array. Therefore, accurate measurements of the roll angle are crucial for the volumetric array to fulfill its potential of fine-scale acoustic tracking.

There are several different operational scenarios within which cetacean assessment operations may be improved with the incorporation of a volumetric array. Significant advantages can be gained by simply having the ability to obtain bearings from the ship without the left/right ambiguity. For example, confirmation of the species identity and group size of acoustically detected animals by visual observers may be achieved more effectively and efficiently to provide additional data for several acoustic projects, including species-identification tools and acoustic proxies for group size estimates.

Several cetacean species form loosely associated, widely-dispersed subgroups that are difficult to track both visually and with current linear arrays. Finer-scale acoustic tracking of these species using a volumetric array may allow for more accurate enumeration of subgroups and provide critical data for the abundance estimation process. More precise bearing information from a volumetric array would also provide insight into the movement patterns of animal groups relative to the research vessel. Attractive or evasive movements prior to detection can create biases in the abundance estimates, especially when these movements frequently occur for a particular species.

Additionally, the ability to determine the relative depth of animal groups using a volumetric array may improve the data collected for deep-diving, cryptic species, such as beaked whales. Visual sightings often lack species identity information due to the brief period that these species spend at the surface. By acoustically tracking animals at depth, their surfacing can be predicted and the research vessel positioned to increase the probability of seeing the group. Declination angles are also needed to accurately estimate perpendicular sighting distance for line-transect abundance estimation.

Overall, there is great potential for a volumetric array to contribute to improving the methods for collecting visual and acoustic cetacean data. The lessons learned from this project offer important information to be used in pursuing the next direction for creating a fully-functional volumetric array for towing at high speeds.

ACKNOWLEDGEMENTS

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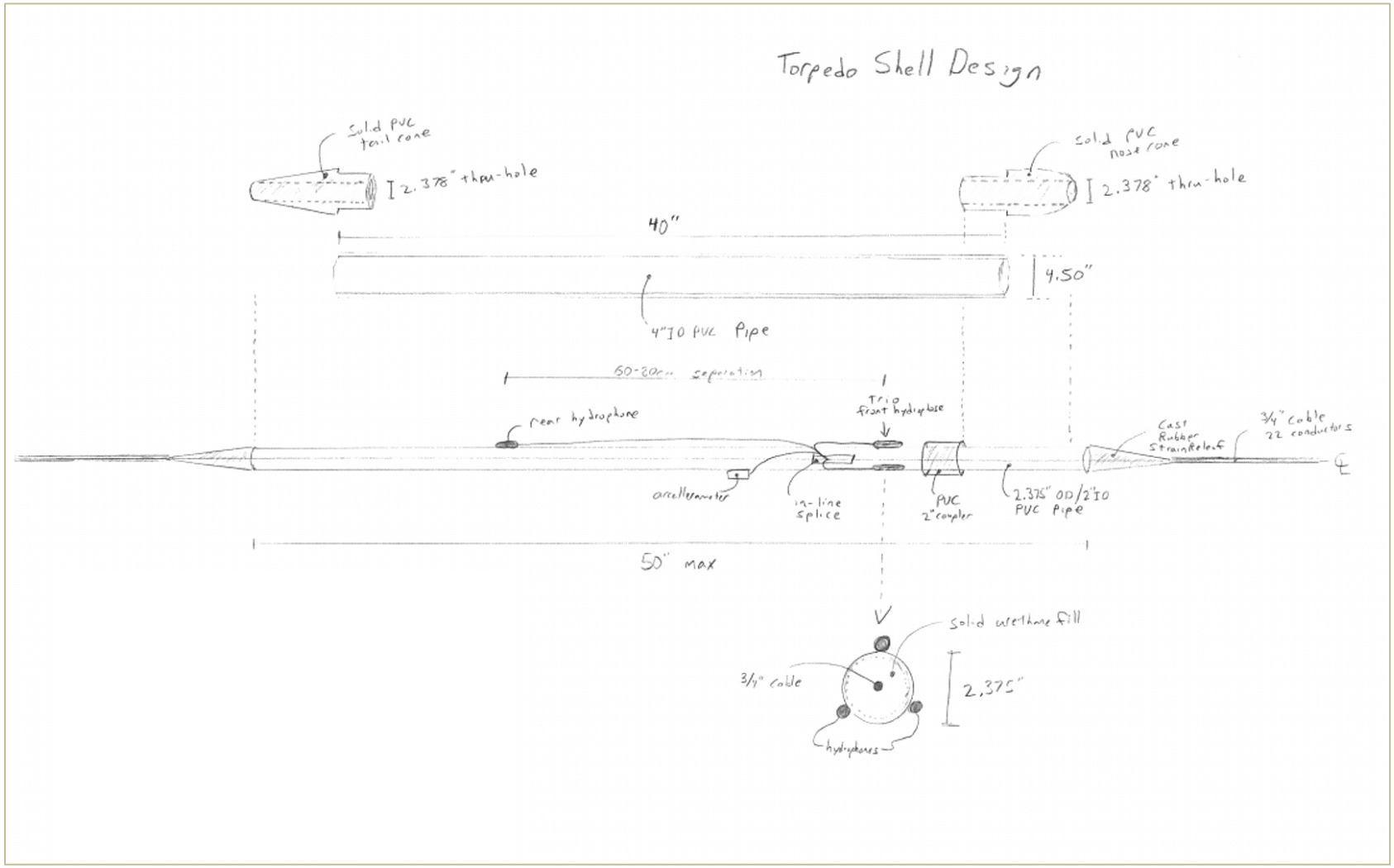
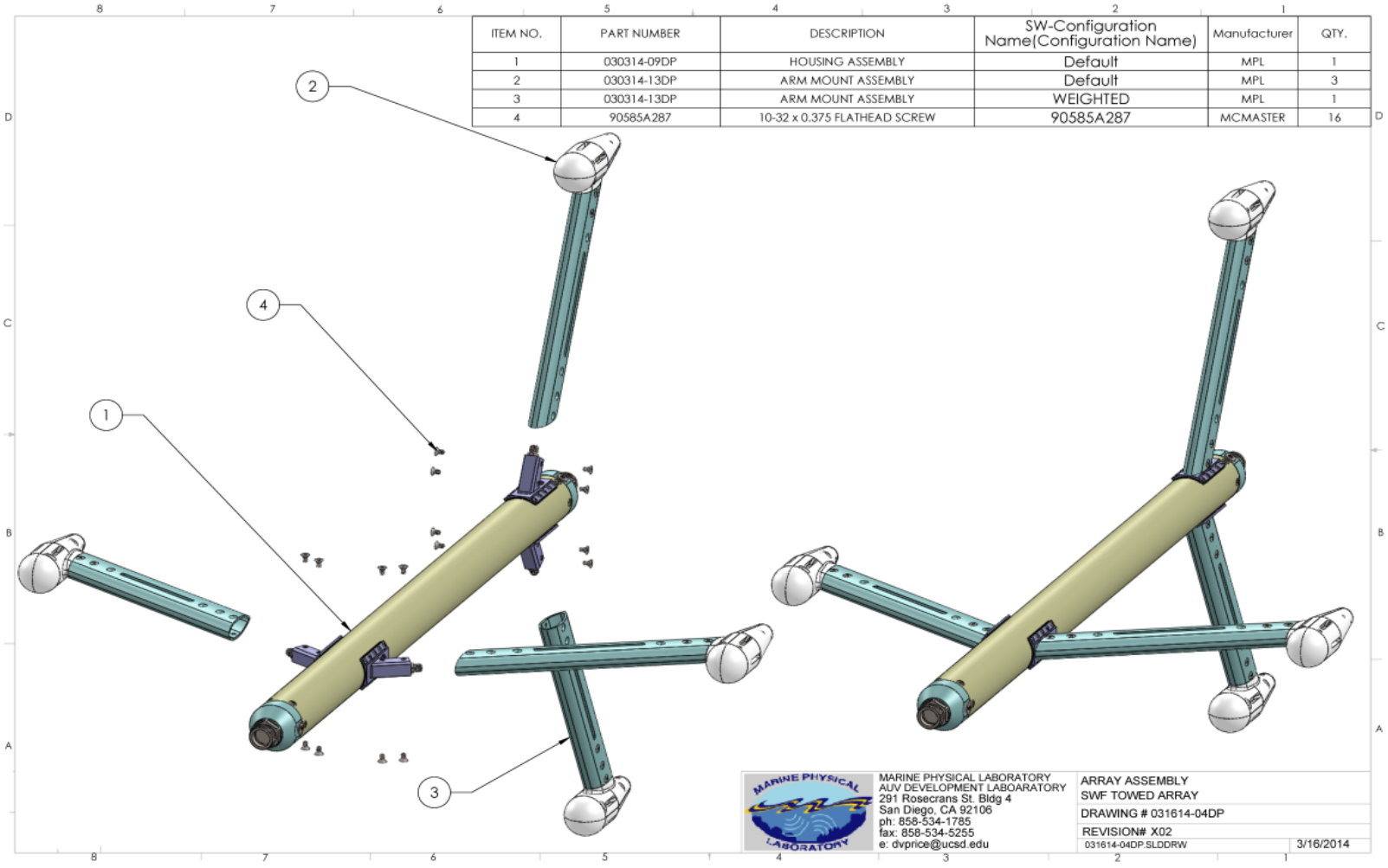
APPENDIX A—Drawings of Volumetric Array Prototypes

Torpedo Array Prototype

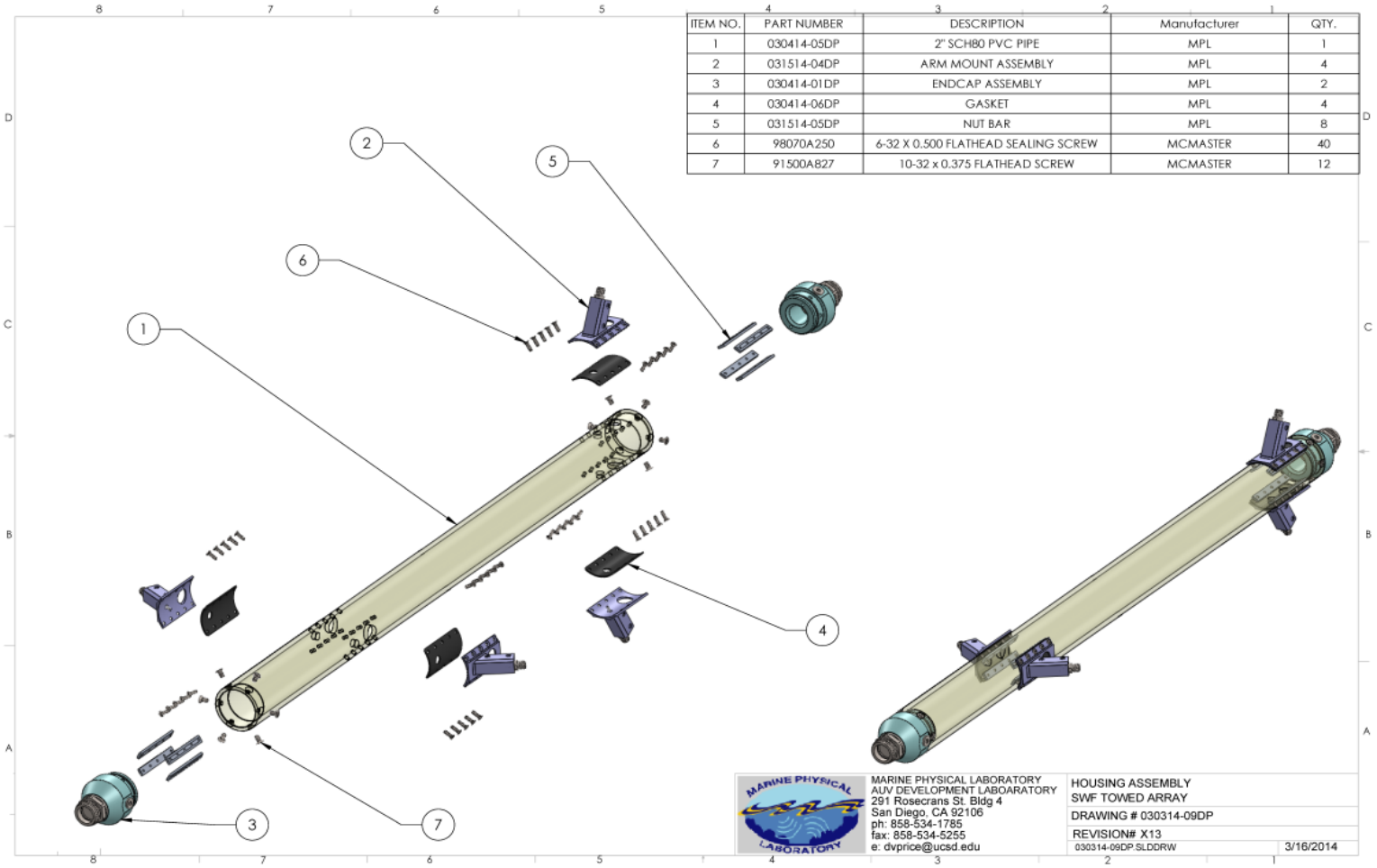


X-Array Prototype

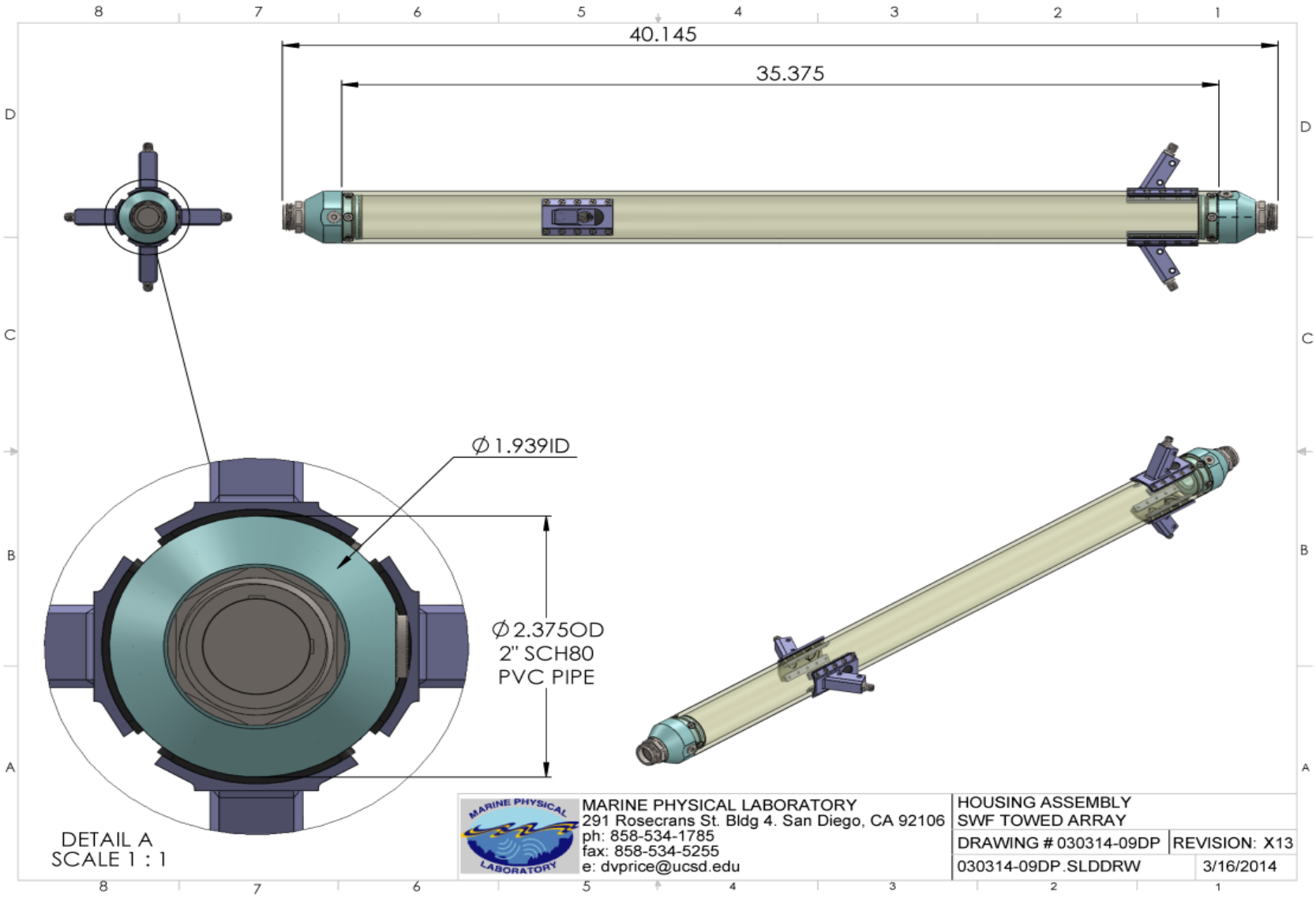
Overview



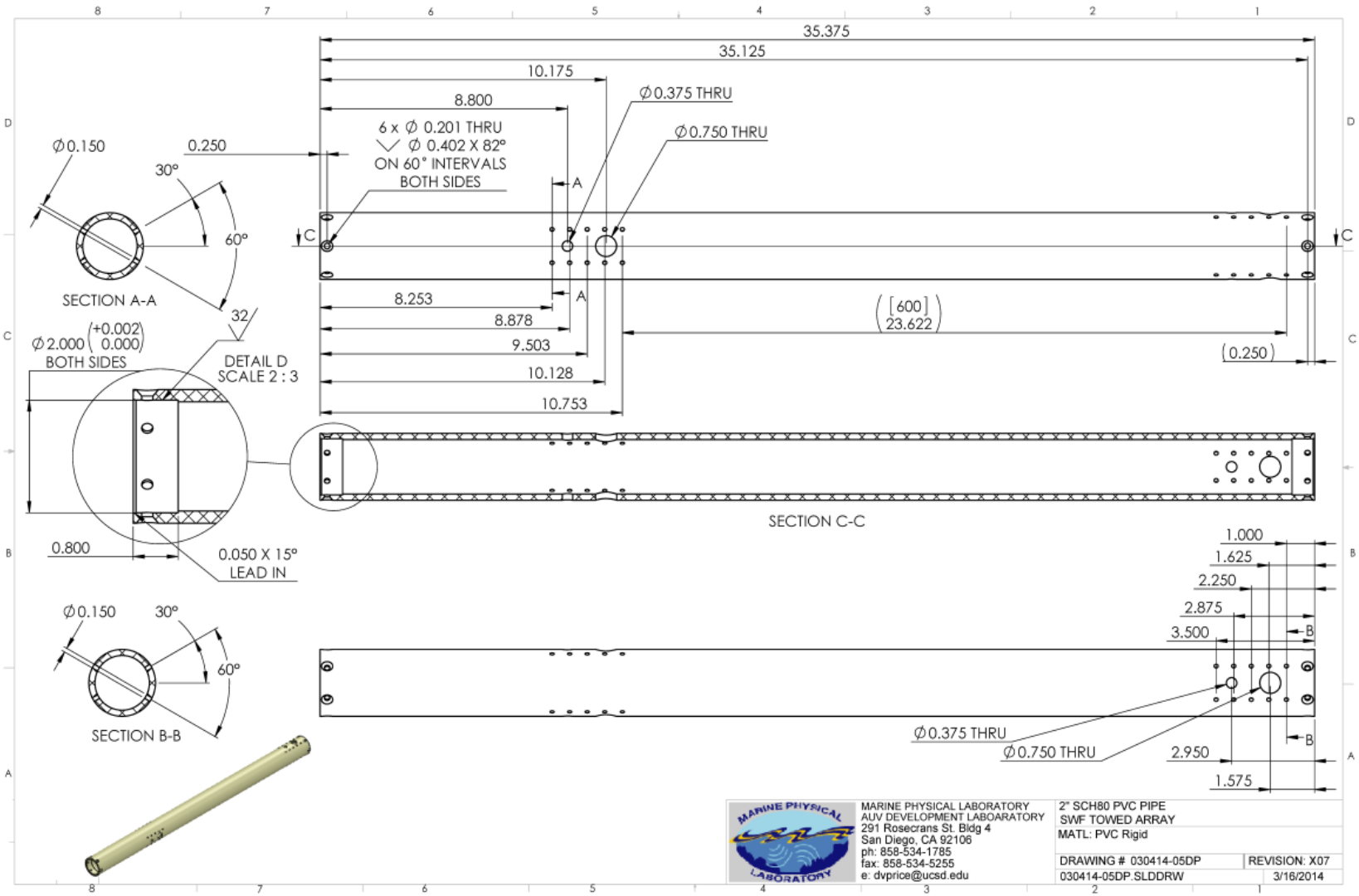
Array Body Assembly



Array Body Dimensions

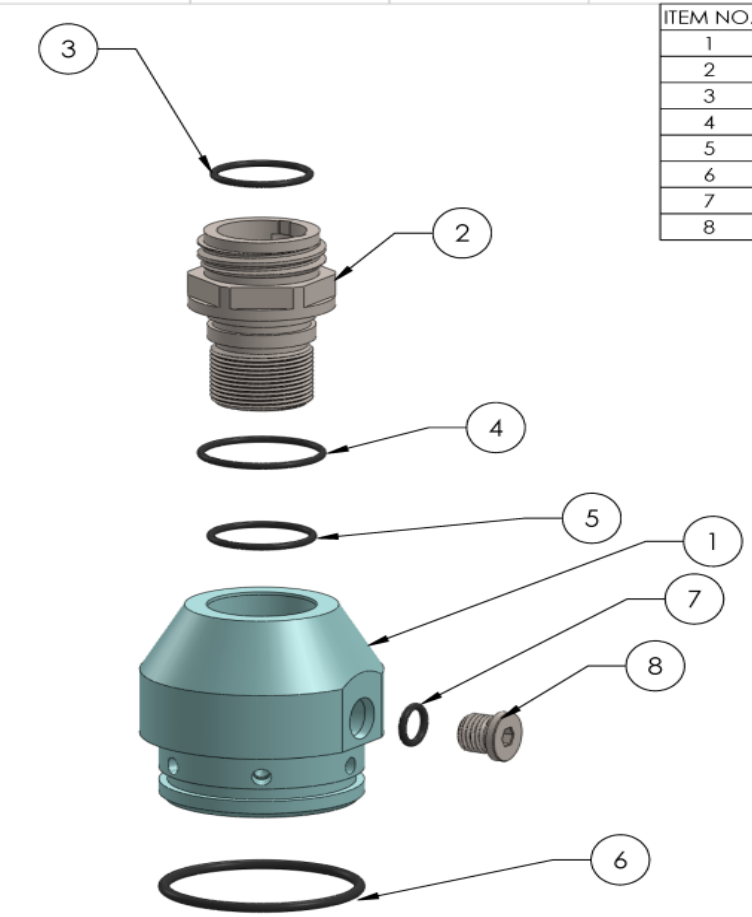


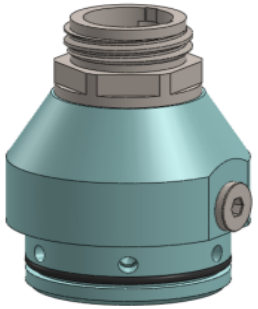
Array Body Detailed Dimensions



Array Body End Cap Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	Manufacturer	Default/QTY.
1	030414-02DP	ENDCAP	MPL	1
2	MHDM-XX-BCR	BULKHEAD CONNECTOR	IMPULSE	1
3	2-020	O-RING	MCMASTER	1
4	2-024	O-RING	MCMASTER	1
5	2-021	O-RING	MCMASTER	1
6	2-133	O-RING	MCMASTER	1
7	3-904	O-RING	MCMASTER	1
8	4-HP5ON-SS	HYDRAULIC FITTING PLUG	PARKER	1





MARINE PHYSICAL LABORATORY
291 Rosecrans St. Bldg 4. San Diego, CA 92106
ph: 858-534-1785 fax: 858-534-5255
e: dvprice@ucsd.edu

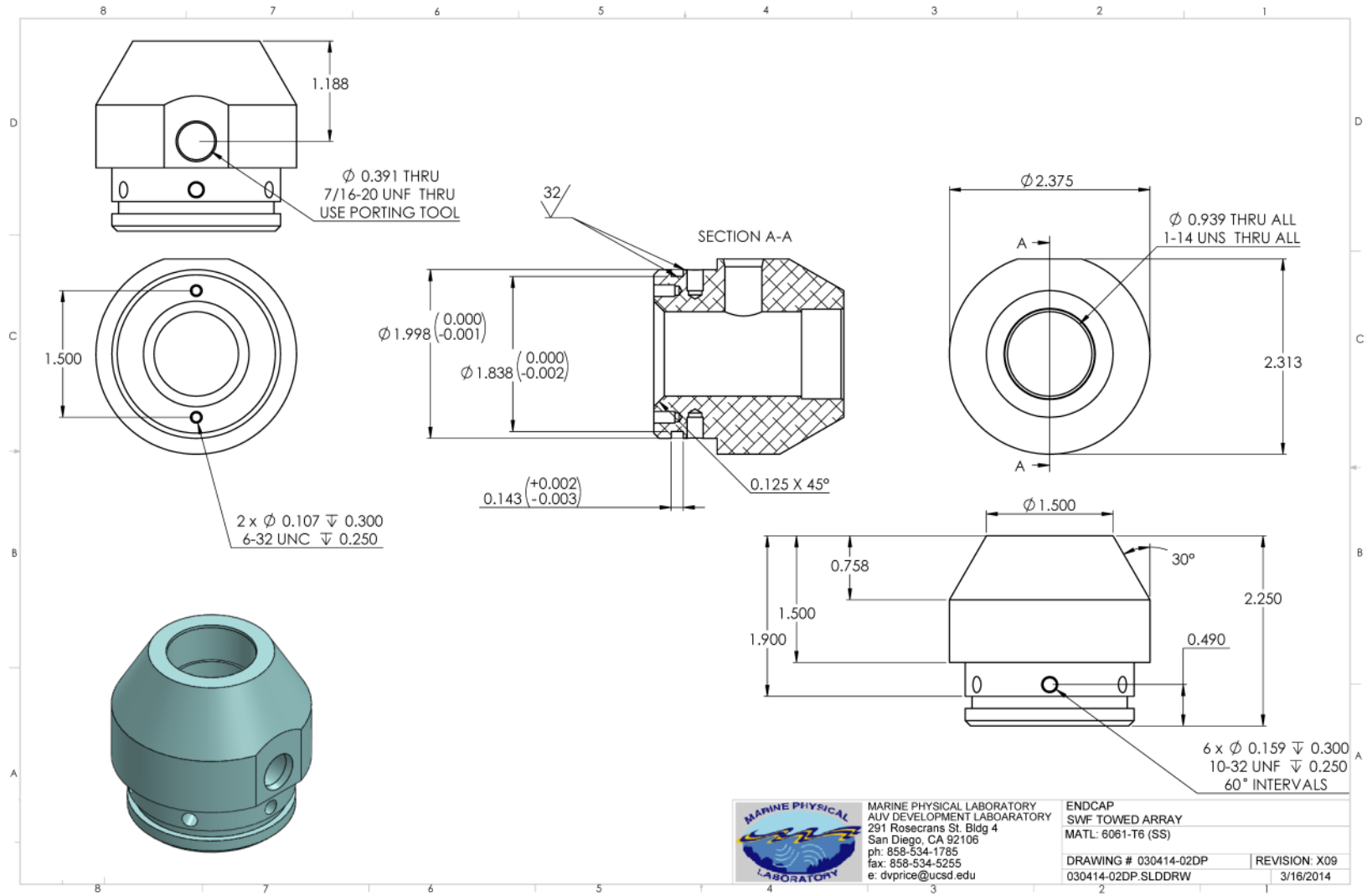
MATL:

DRAWING # 030414-01DP
REVISION: X05

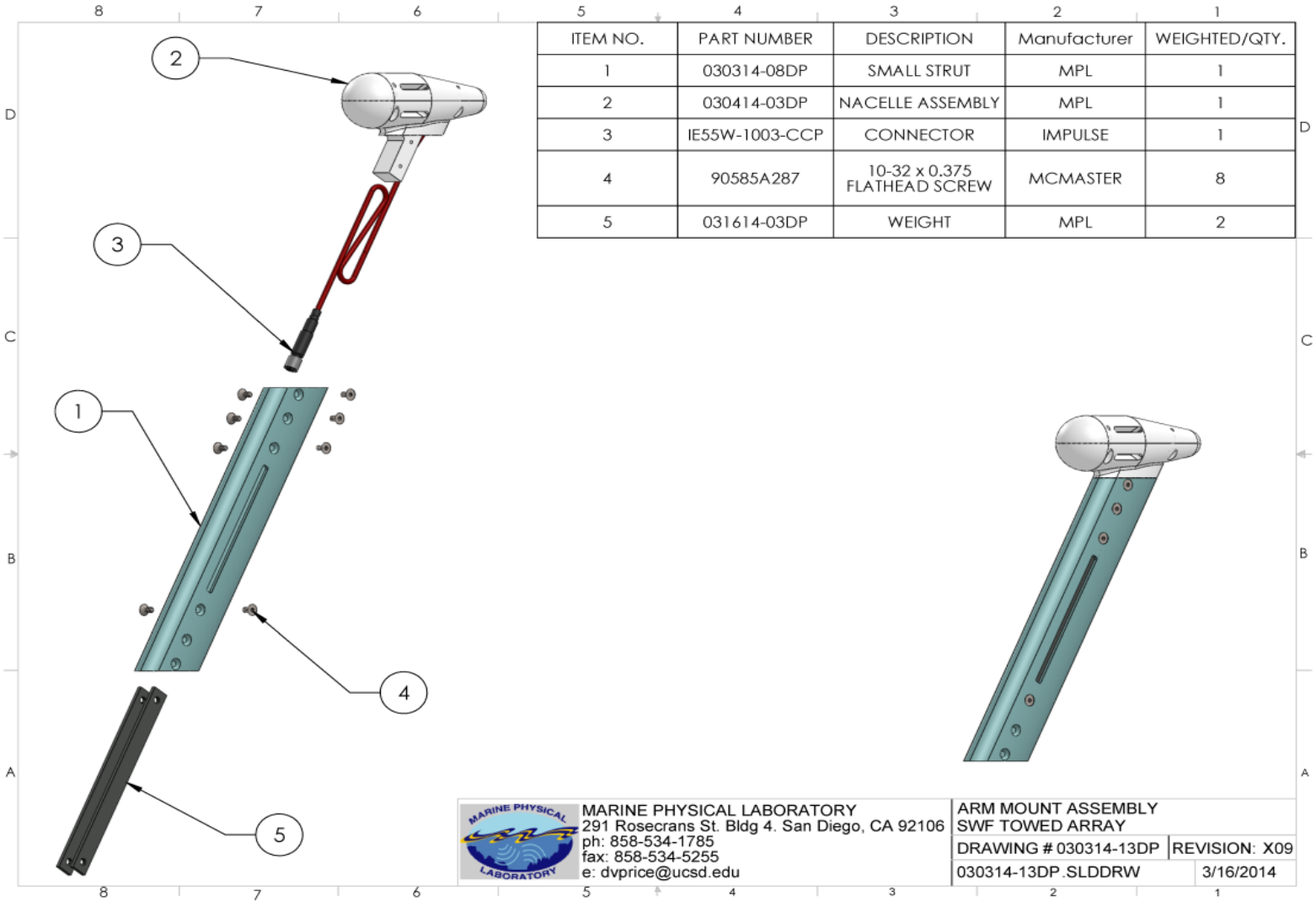
UNLESS OTHERWISE SPECIFIED: TOLERANCES: 3-PL DEC ± 0.005, 2-PL DEC ± 0.01
DIMENSIONS IN INCHES ANGLES ± 1.0°
BREAK SHARP EDGES FRACTIONS ± 1/64

ENDCAP ASSEMBLY
SWF TOWED ARRAY
030414-01DP.SLDDRW 3/16/2014

Array Body End Cap Dimensions



Strut and Hydrophone Pod (Nacelle) Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	Manufacturer	WEIGHTED/QTY.
1	030314-08DP	SMALL STRUT	MPL	1
2	030414-03DP	NACELLE ASSEMBLY	MPL	1
3	IE55W-1003-CCP	CONNECTOR	IMPULSE	1
4	90585A287	10-32 x 0.375 FLATHEAD SCREW	MCMASTER	8
5	031614-03DP	WEIGHT	MPL	2

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291 Rosecrans St. Bldg 4. San Diego, CA 92106
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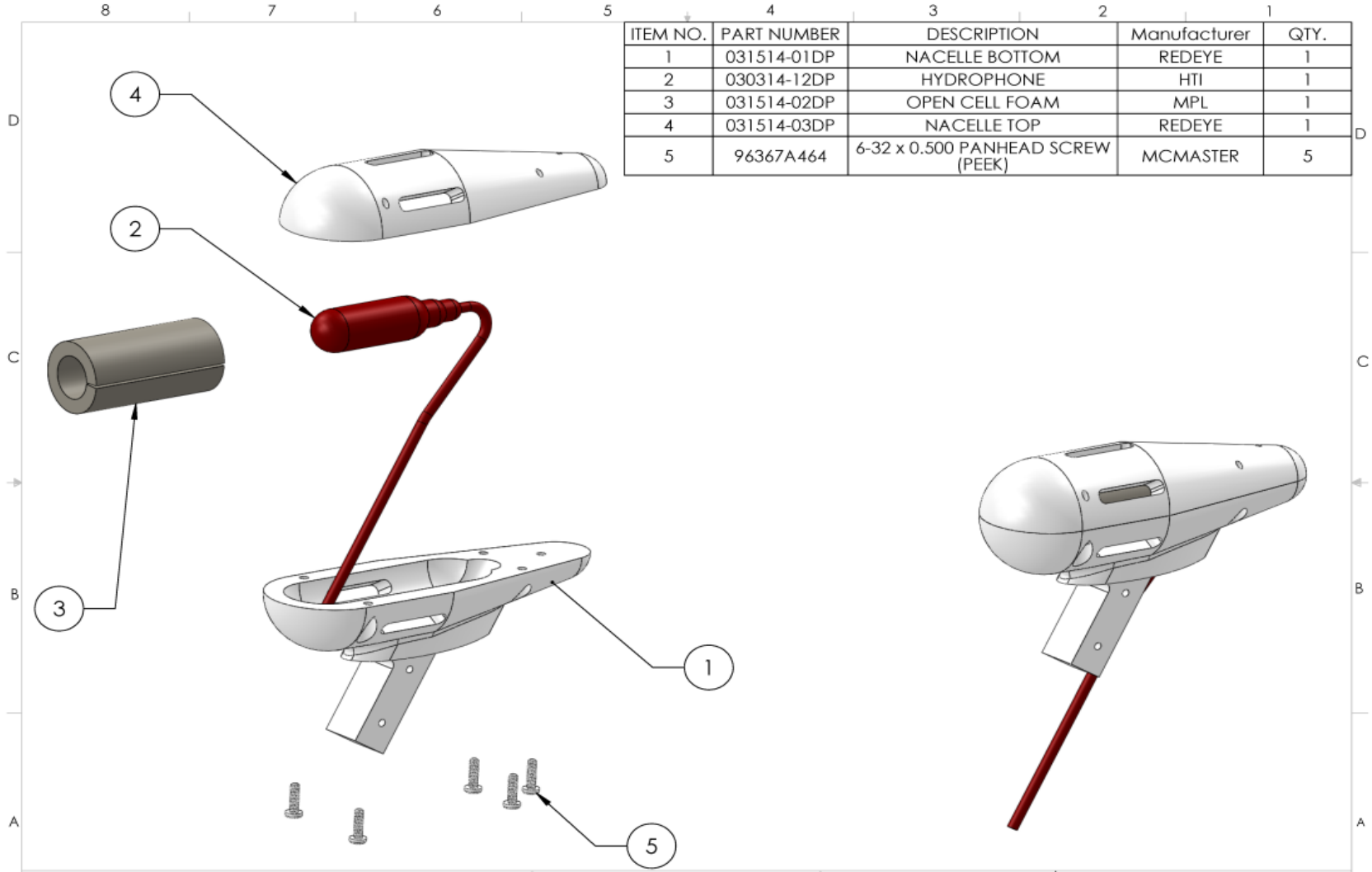
fax: 858-534-5255
e: dvprice@ucsd.edu

ARM MOUNT ASSEMBLY
SWF TOWED ARRAY
DRAWING # 030314-13DP | REVISION: X09
030314-13DP.SLDDRW | 3/16/2014

Hydrophone Pod Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	Manufacturer	QTY.
1	031514-01DP	NACELLE BOTTOM	REDEYE	1
2	030314-12DP	HYDROPHONE	HTI	1
3	031514-02DP	OPEN CELL FOAM	MPL	1
4	031514-03DP	NACELLE TOP	REDEYE	1
5	96367A464	6-32 x 0.500 PANHEAD SCREW (PEEK)	MCMASTER	5



MARINE PHYSICAL LABORATORY
291 Rosecrans St. Bldg 4. San Diego, CA 92106
ph: 858-534-1785 fax: 858-534-5255
e: dvprice@ucsd.edu

MATL:

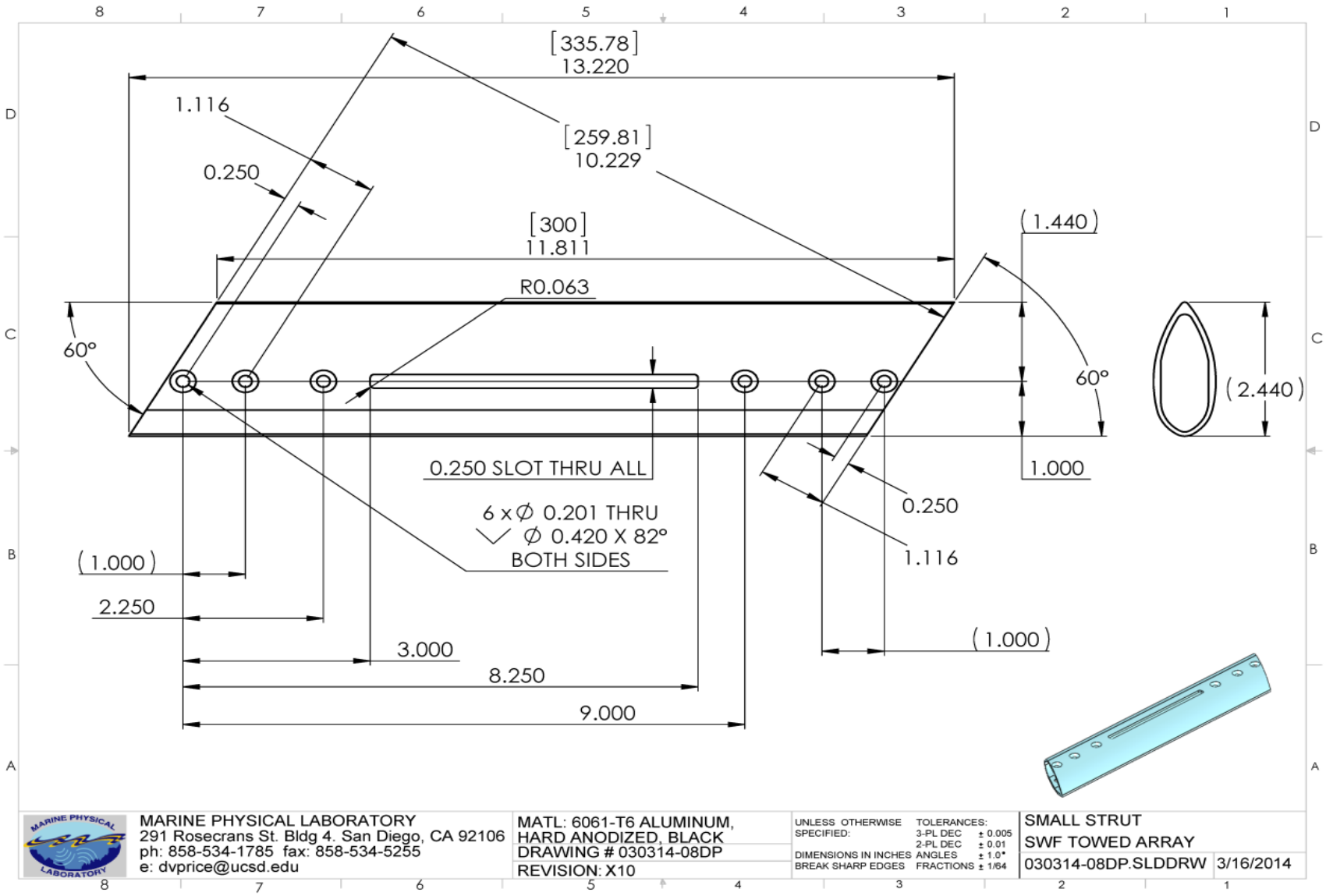
DRAWING # 030414-03DP

REVISION: X03

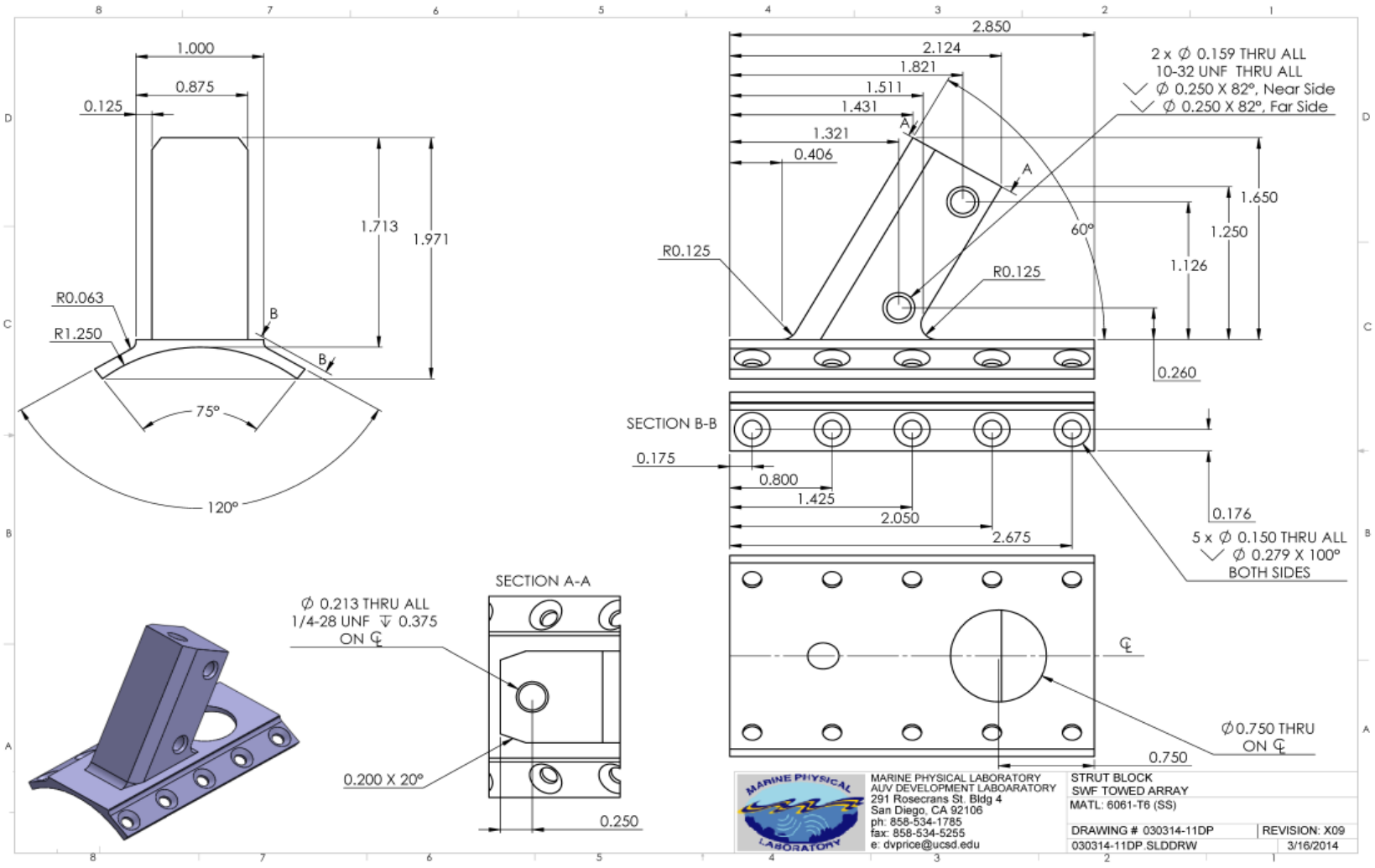
UNLESS OTHERWISE SPECIFIED: TOLERANCES: 3-PL DEC ± 0.005, 2-PL DEC ± 0.01
DIMENSIONS IN INCHES ANGLES ± 1.0°
BREAK SHARP EDGES FRACTIONS ± 1/64

NACELLE ASSEMBLY
SWF TOWED ARRAY
030414-03DP.SLDDRW 3/16/2014

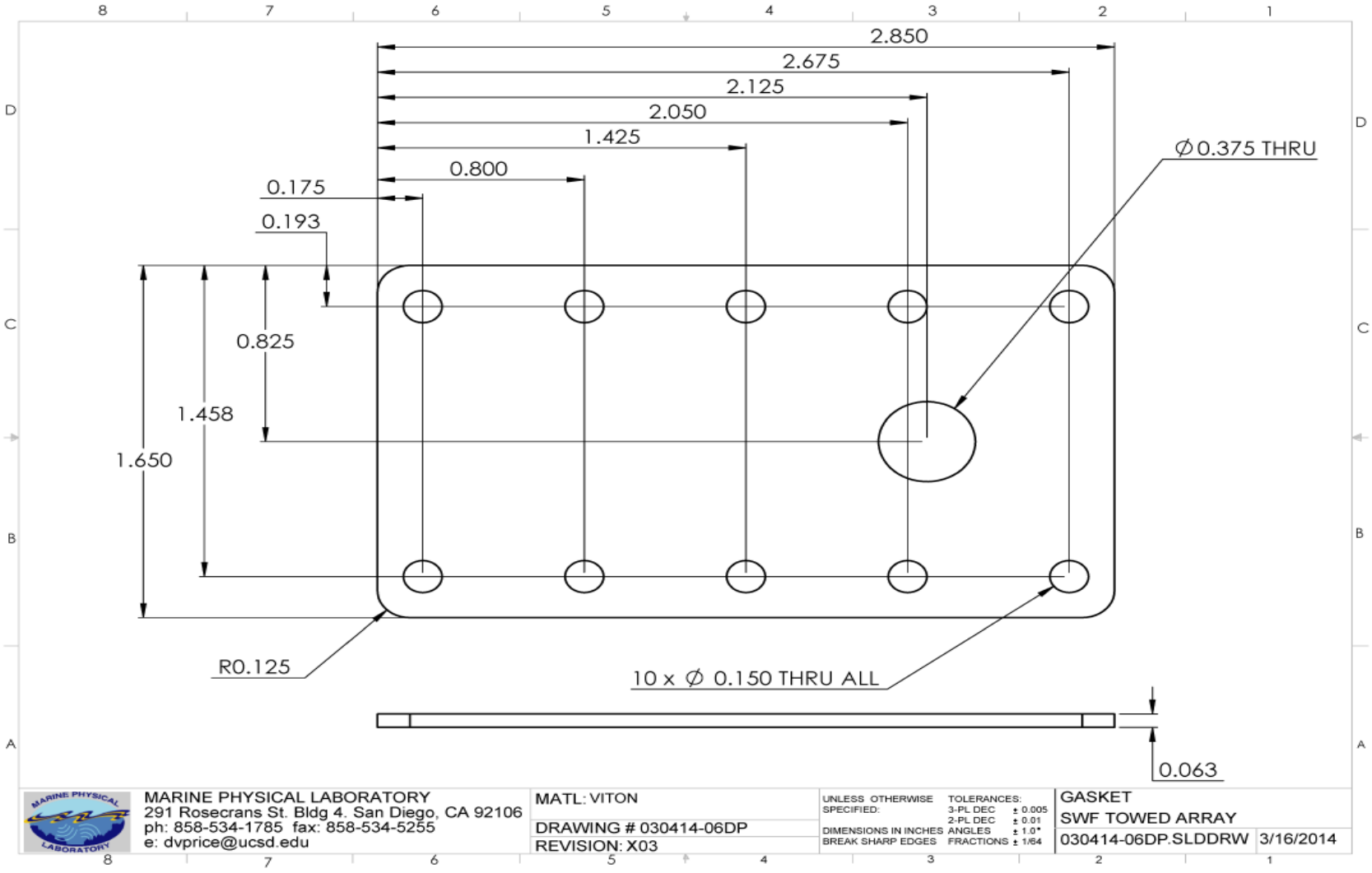
Strut Dimensions



Strut Block Dimensions



Gasket Dimensions



APPENDIX B—Specifications for Components Implemented into the Volumetric Array Prototypes for Compatibility with Current NMFS PAM Systems

Hydrophone Specifications

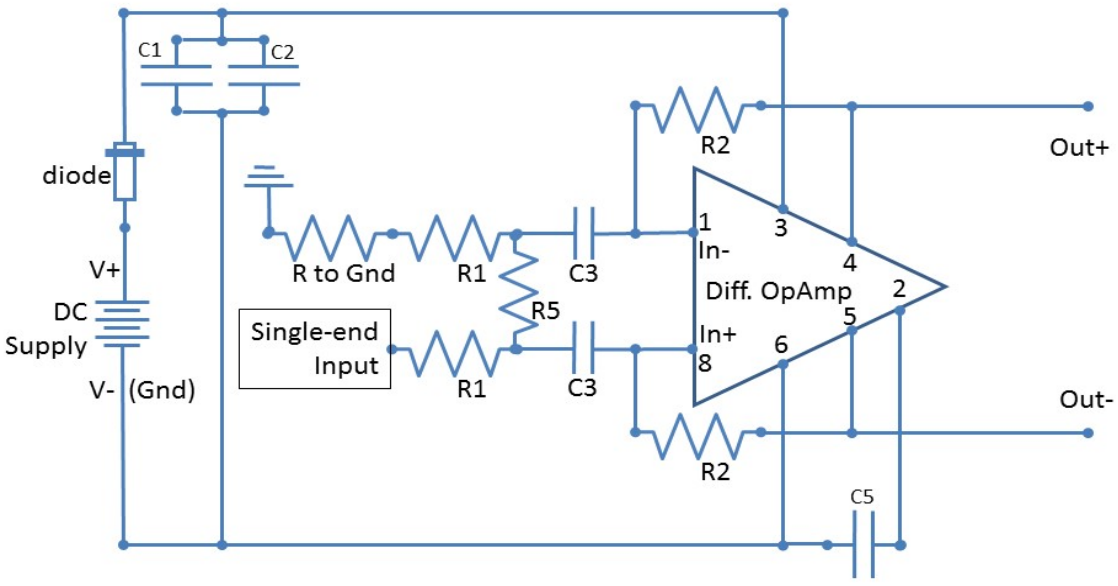
High Tech, Incorporated

- HTI-96-MIN Exportable

Differential Preamp

Designed by Jay Barlow, 2012

Schematic for differential output pre-amp with single-ended input & high-pass filter.



DC Supply Voltage
OPA1632 OpAmp 5-32 V
THS4521 OpAmp 2.5-5.5 V

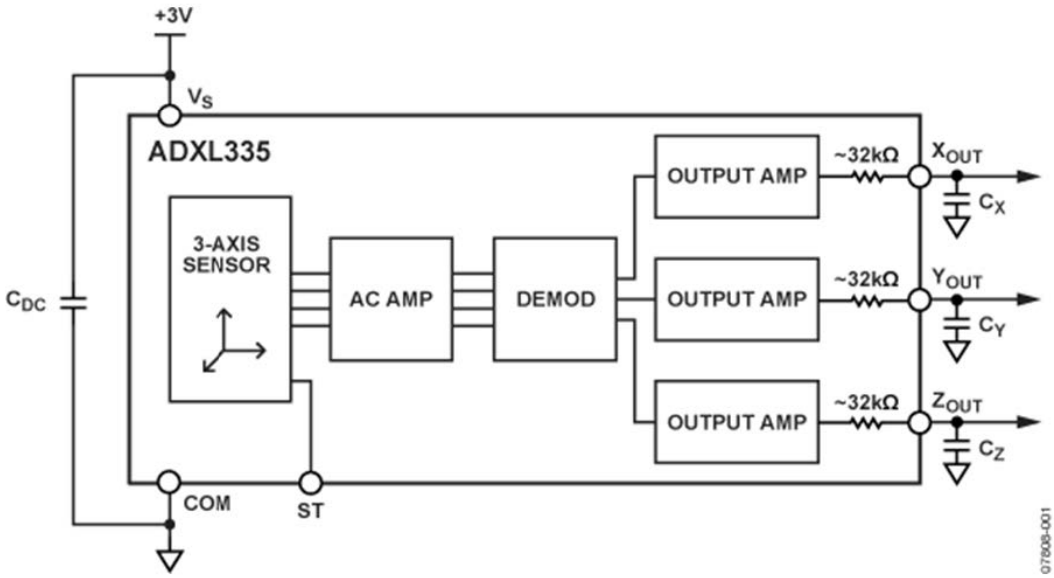
Use ceramic capacitors and 1/8W metal-film resistors.

Example values: gain = 40 dB
highpass= 1.6 kHz

R1= 100 Ω	C1= 22 µF
R2= 10K Ω	C2= 0.1 µF
R5= n/a Ω	C3= 1 µF
R-gnd= 10 Ω	C5= 1 µF

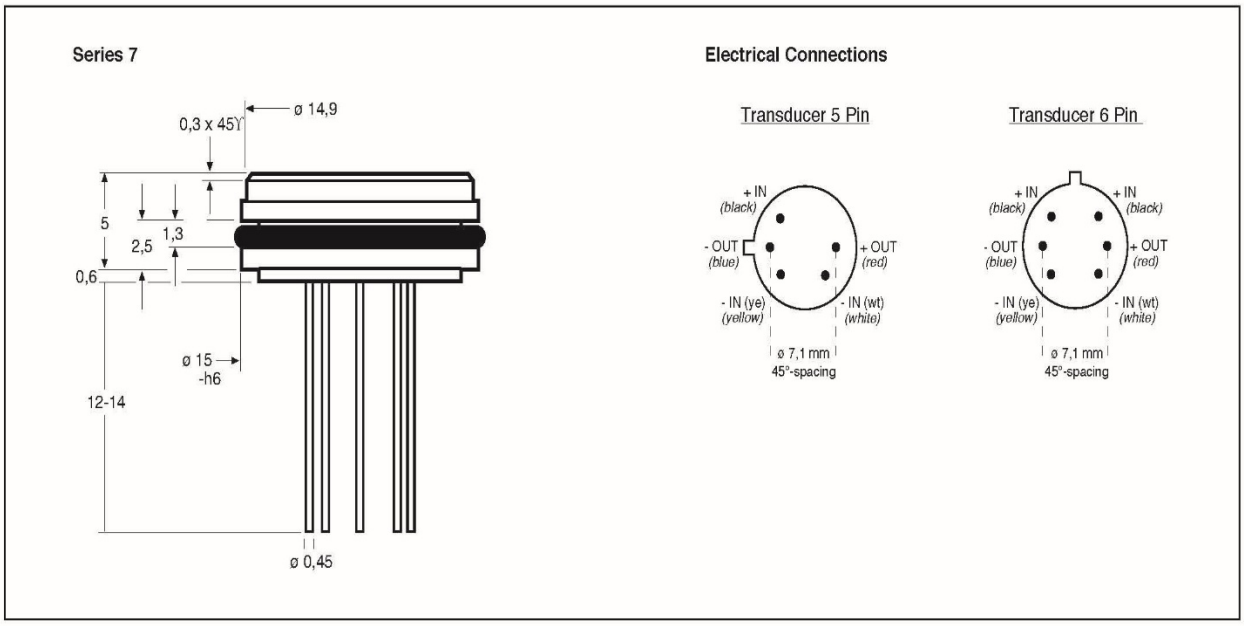
Accelerometer

Adafruit triple axis analog accelerometer – ADXL335



Depth Sensor

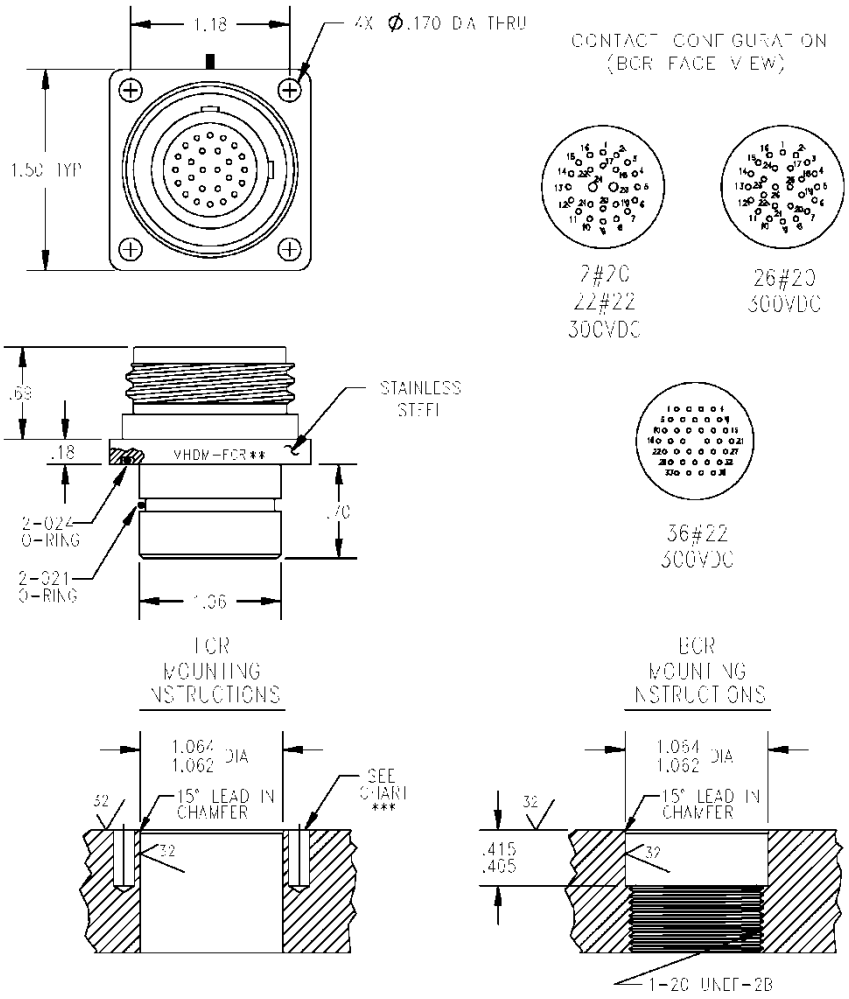
Keller America Series 7 pressure sensor – PA7FLE, 0-20 Bar, 4-20mA



Underwater Connector Specifications

Teledyne Impulse Miniature High Density Series 26-pin Connector

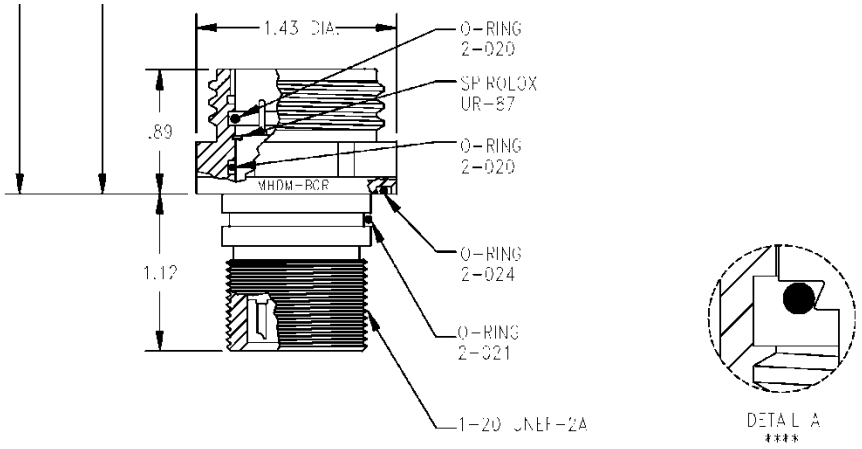
MHDM MINIATURE HIGH DENSITY SERIES TELEDYNE IMPULSE



MOUNTING TORQUE FOR BCR	not to exceed 200 in lbs	MATED PRESSURE RATING (psi)	10,000
DUMMY PLUG FOR BCR	MHDM-SCP	DUMMY PLUG FOR CCP	MHDM-SCR

NOTE: CCP is not terminated to cable unless specified.
* Please specify number of contacts.
** Interna assembly is the same as the MHDM-BCR (facing page).
*** Blind tapped hole not to penetrate bulkhead, minimum full thread depth 2 times bolt diameter.
**** O-Ring installation tool available – Contact factory for further details.

Teledyne Impulse Miniature High Density Series 26-pin Connector, *continued.*



1-800-327-0971 © 2009 Teledyne Impulse

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47 Revised stock boundaries for false killer whales (Pseudorca crassidens) in Hawaiian waters.
A. L. BRADFORD, E. M. OLESON, R. W. BAIRD, C. H. BOGGS, K. A. FORNEY, and N. C. YOUNG
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K. S. GRAHAM, C H. BOGGS, E. E. DEMARTINI, R. E. SCHROEDER, and M. S. TRIANNI
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